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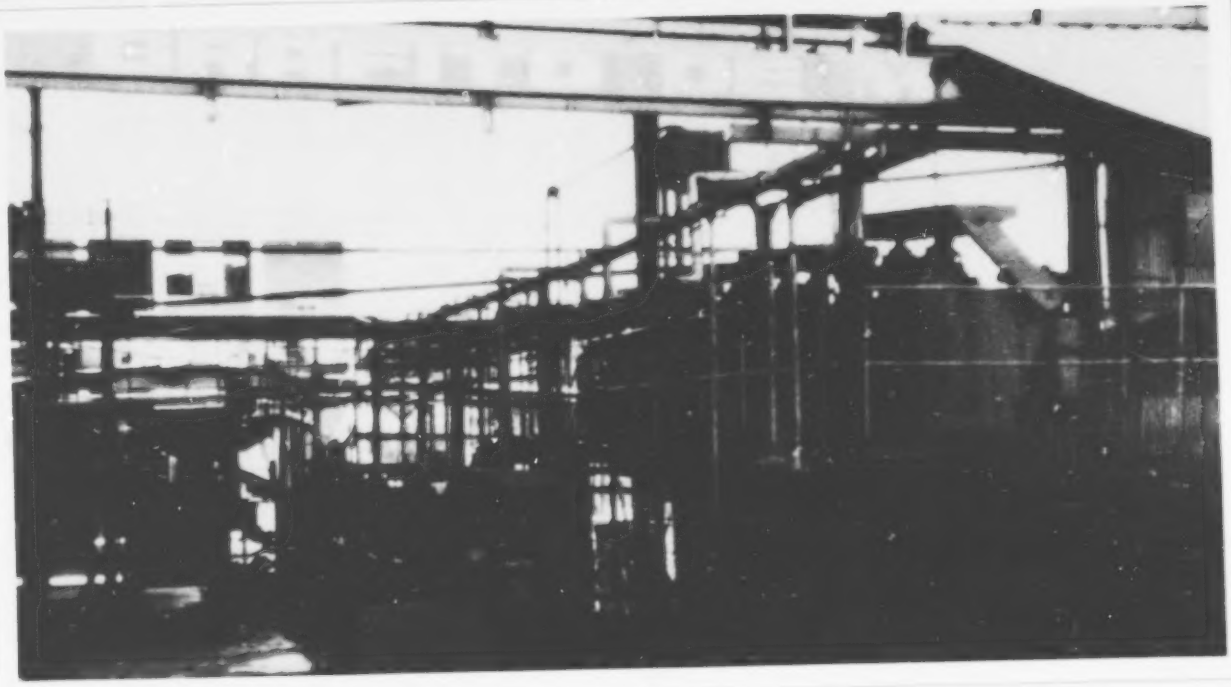

GRAPHITE

By Harold A. Taylor, Jr.

1989

U.S. DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

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GRAPHITE

U.S.
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Secretary

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Director

September 1990

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COVER PHOTO:
Beneficiating crystalline flake graphite ore, Oaxaca State, Mexico.

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For comments and further information, please contact
Branch of Industrial Minerals
Division of Mineral Commodities
Bureau of Mines
2401 E Street, NW, MS 5209
Washington, DC 20241-0001
Telephone: (202) 634-1180
Fax: (202) 634-4091

GRAPHITE

By Harold A. Taylor, Jr.

Physical scientist, Branch of Industrial Minerals. He has covered graphite for 10 years. Domestic survey data prepared by Joseph Daniels, mineral data assistant, Branch of Data Collection and Coordination. International data prepared by Audrey Wilkes, international data assistant, Geographic Data Section.

Amorphous graphite was mined domestically in 1989. Graphite supplies, particularly of fine crystalline flake, lagged behind industrial demand, which increased substantially from the previous year. Prices of the major imported graphites generally increased from those of 1988. Production of manufactured graphite and graphite fibers decreased slightly and increased by 21% respectively.

DOMESTIC DATA COVERAGE

Domestic production data for synthetic graphite are developed by the Bureau of Mines from a voluntary survey of domestic producers. Of the 33 operations polled, 100% responded. This represented 100% of the total production data shown in table 4.

LEGISLATION AND GOVERNMENT PROGRAMS

No acquisitions or disposal of graphite from the strategic and critical materials stockpile occurred in 1989. However, new and smaller goals were authorized but not implemented, as follows: 12,882 metric tons for Madagascar crystalline flake and 1,751 tons for crystalline graphite other than Madagascar and Sri Lanka. The following amounts of graphite were authorized for disposal: up to 3,298 tons of Madagascar crystalline flake and up to 792 tons of crystalline graphite other than Madagascar and Sri Lanka.

PRODUCTION

United Minerals Co. operated its Townsend, MT, mine in 1989. Output of manufactured graphite decreased slightly to about 270,000 tons, at 30 plants, with a likelihood of some unreported production for in-house use. Production of all kinds of graphite fiber and cloth increased 21% to 2,915 tons. Union Carbide Corp. continued to operate its Puerto Rican graphite electrode plant in 1989, on an interim basis.

TABLE 1

SALIENT NATURAL GRAPHITE STATISTICS

		1985	1986	1987	1988	1989
United States:						
Production	metric tons	—	—	—	W	W
Apparent consumption	do.	40,261	31,784	31,634	42,799	50,867
Exports	do.	7,581	7,034	11,700	11,068	11,452
Value	thousands	$3,125	$3,416	$6,218	5,815	7,421
Imports for consumption	metric tons	47,842	38,818	43,334	53,867	62,319
Value	thousands	$16,186	$15,758	$17,654	$23,238	33,707
World: Production	metric tons	r583,779	r624,718	r648,156	p643,938	e634,050

eEstimated. pPreliminary. rRevised. W Withheld to avoid disclosing company proprietary data.

TABLE 2

U.S. GOVERNMENT STOCKPILE GOALS AND YEAREND STOCKS OF NATURAL GRAPHITE IN 1989, BY TYPE

(Metric tons)

Type	Goal	National stockpile inventory
Madagascar crystalline flake	18,144	16,171
Sri Lanka amorphous lump	5,715	4,934
Crystalline, other than Madagascar and Sri Lanka	2,540	1,754
Nonstockpile-grade, all types	—	846

Source: General Services Administration, Inventory of Stockpile Materials as of Dec. 31, 1989.

CONSUMPTION AND USES

Reported consumption of natural graphite increased 9% to about 37,400 tons. The three major uses of natural graphite were refractories, lubricants, and foundries, which together accounted for 59% of reported consumption.

Nonclay refractories represent two important use categories of graphite. Standard refractory products, particularly gunning and ramming mixes, accounted for a sizeable part of the demand in the past 5 years, mainly as amorphous graphite. Crucibles, shrouds, nozzles, stopper heads, and retorts, used in hot metal processing operations such as the continuous casting of steel, use significant amounts of crystalline flake. High-purity coarse flake graphite is preferred for crucibles and refractory associated items, but generally it is mixed with some fine crystalline material of lower value. The newest impor

TABLE 3

PRINCIPAL PRODUCERS OF SYNTHETIC GRAPHITE IN 1989

Company	Plant location	Product[1]
Akzo-Enka America Inc., Fortafil Fiber Div.	Rockwood, TN	High-modulus fibers.
Amoco Performance Products	Greenville, SC	Cloth, high-modulus fibers.
Ashland Petroleum Co., Carbon Fibers Div.	Ashland, KY	High-modulus fibers.
BASF Structural Materials Inc.	Rock Hill, SC	Do.
Courtaulds Grafil Co.	Sacramento, CA	Do.
Fiber Materials Inc.	Biddeford, ME	Other.
Fiber Technology Corp.	Provo, UT	
BF Goodrich Co., Engineered Systems Div., Super Temp Operation	Santa Fe Springs, CA	Other.
Great Lakes Carbon Corp.		
Do.	Morganton, NC	Electrodes, unmachined shapes, motor brushes, other.
Do.	Niagara Falls, NY	
Do.	Ozark, AR	
Hercules Inc.	Salt Lake City, UT	High-modulus fibers.
HITCO Materials Group, British Petroleum Co. Ltd.	Gardena, CA	Cloth and high-modulus fibers.
National Electrical Carbon Co.	Fostoria, OH	Motor brushes, unmachined shapes, cloth.
North American Carbon Inc.	Punxsutawney, PA	Other.
Pfizer Minerals, Pigments & Metals Div.	Easton, PA	Do.
Polycarbon Inc.	Valencia, CA	Cloth.
Showa Denko Carbon Inc.	Ridgeville, SC	Electrodes, other.
Sigri Carbon Corp.	Hickman, KY	
Stackpole Fibers Co., Inc.	Lowell, MA	High-modulus fibers.
The Stackpole Corp., Carbon Div.	St. Mary's, PA	Motor brushes and unmachined shapes.
Standard Oil Co., Specialty Graphite Metallics Div.	Sanborn, NY	Motor brushes, unmachined shapes, cloth.
Superior Graphite Co.	Russellville, AR	Electrodes and other.
Do.	Hopkinsville, KY	
Textron Corp., Avco Specialty Materials Div.	Lowell, MA	High-modulus fibers.
The Carbon/Graphite Group Inc.	Niagara Falls, NY	Anodes, electrodes, unmachined shapes, motor brushes, refractories.
Do.	St. Mary's, PA	
Union Carbide Corp., Carbon Products Div.	Clarksburg, WV	
Do.	Clarksville, TN	Anodes, electrodes, unmachined shapes, crucibles and vessels, other.
Do.	Columbia, TN	
Do.	Yabucoa, PR	

[1] Cloth includes low-modulus fibers; motor brushes include machined shapes, crucibles include vessels.

tant refractory use for graphite in steelmaking is in carbon magnesite brick, where large amounts of crystalline flake are now used.

Graphite is used in brake and clutch linings. More graphite is being used as users change over from asbestos. The graphite lubricates, transfers the heat of friction away from the part, and leads to a lower rate of wear. Graphite is more commonly used in heavier-duty nonautomobile linings. Low-quality crystalline flake and amorphous graphite are suitable for foundry facing use. The graphite is mixed with a small amount of clay, suspended in an adhesive material, and applied as a thin coating to mold surfaces to provide for clean and easy mold release of the metal castings.

Graphite is important as a lubricant and as an ingredient in special packings. When used as a lubricant, it can be a dry powder or mixed with oil or water. It is used with materials that must withstand extreme conditions, such as very high temperatures. Material for this use must be free of abrasive-type impurities.

Some interchange of the various types and grades of natural graphite and between manufactured and natural graphite takes place, but the degree is difficult to determine. Manufactured graphite does not compete with natural graphite in most uses because of its greater cost. Manufactured graphite is not substitutable for natural flake graphite in clay-bonded graphite crucibles, although some crucibles are machined from manufactured graphite for special uses. Calcined coke and other

TABLE 4

U.S. PRODUCTION OF SYNTHETIC GRAPHITE, BY USE

Use	1988		1989	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Products:				
Anodes	6,827	$17,399	6,196	$18,144
Cloth and fibers (low-modulus)	239	28,228	377	34,846
Crucibles, vessels, refractories	W	W	W	W
Electric motor brushes and machined shapes	W	W	W	W
Electrodes	r192,959	r382,538	188,264	379,196
Graphite articles[1]	—	35,656	—	32,492
High-modulus fibers	2,176	117,754	2,538	128,603
Unmachined graphite shapes	5,033	33,258	4,584	27,297
Other	6,542	47,881	6,201	57,516
Total	r213,776	r662,714	208,160	678,094
Synthetic graphite powder and scrap	r63,939	r34,648	62,259	28,574
Grand total	r277,715	r697,362	270,419	706,668

r Revised. W Withheld to avoid disclosing company proprietary data; included with "Other."
[1] Includes all items for which no quantity data is available.

TABLE 5

U.S. PRODUCTION OF GRAPHITE FIBERS

Year	Cloth and low-modulus fibers		High-modulus fibers		Total	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1979	153	$10,089	176	$13,031	329	$23,120
1980	153	11,254	278	17,379	431	28,633
1981	196	15,293	371	21,759	567	37,052
1982	192	17,706	549	30,091	741	47,797
1983	171	14,217	670	33,854	841	48,071
1984	202	17,979	1,052	56,436	1,254	74,415
1985	287	27,235	1,439	84,743	1,726	111,978
1986	149	17,895	1,373	76,622	1,522	94,517
1987	231	23,706	1,583	84,559	1,814	108,265
1988	239	28,228	2,176	117,754	2,415	145,982
1989	377	34,846	2,538	128,603	2,915	163,449

carbons are satisfactory substitutes for graphite for certain foundry core and mold washes and are used when they can compete in terms of price and supply. Other carbons with high purity can be used in batteries.

PRICES

Natural graphite prices are often negotiated between the buyer and seller and are based on purity and other criteria. Therefore, published price quotations such as those in Industrial Minerals are given as a range of prices. Another source of information for graphite prices is the average customs value per ton of the different imported classes. These mainly represent shipments of unprocessed graphite. A third source for natural graphite prices is the amount paid per ton at the point of consumption.

The price for crystalline graphite at the point of consumption—mostly crystalline flake, some crystalline dust, and a little lump graphite—rose by 27% to $1,540 per ton. The price for amorphous graphite (including small amounts of amorphous-synthetic graphite mixtures) rose by 5% to $707 per ton.

FOREIGN TRADE

The United States changed its tariff classification to the Harmonized Code on January 1, 1989. This has rendered the 1988 and 1989 import and export statistics to be somewhat noncomparable. The statistics for imports of artificial graphite are completely noncomparable; actual activity is believed to be fairly similar in both years.

Total exports of natural graphite decreased slightly. Exports of graphite electrodes totaled 97,307 tons valued at $142.6 million, of which 32,966 tons ($20.3 million) went to Canada, 11,474 tons ($15.0 million) to Brazil, 11,161 tons ($22.4 million) to Japan, 7,051 tons ($15.6 million) to Venezuela, 3,542 tons ($9.2 million) to the Federal Republic of Germany, and the balance to other destinations.

Imports of natural graphite increased 16% from those of 1988. Imports of natural graphite from Canada, China, the Republic of Korea, and Madagascar rose substantially.

WORLD REVIEW

The current year has been interesting and murky, as we watched two major developments being played out. At yearend 1988, the Chinese announced some major price increases in crystalline flake coupled with a cutback in exports of 40,000 to 50,000 tons. They stated that this resulted from a drought which affected the water supply for beneficiation and transportation, greater internal consumption, and the closure of economically marginal mines. The higher prices continued to be posted throughout the year. A high Bureau official was told earlier by the Chinese

that industrial mineral prices at the October 1989 Canton Fair would be "very competitive." In spite of this supposed cutback, the actual Chinese graphite exports to major markets changed little from 1988. No drop off was observed towards the end of the year. The demand by actual consumers such as the steel industry held up well, and it was probably even stronger than 1988. Against this backdrop, a number of Canadian would-be graphite producers struggled to come on-stream to fill this perceived gap. New capacity came on-stream in Norway and Mexico which also offset the shortfall in production.

Australia

Gwalia Minerals NL entered into a joint venture with a London-based merchant banker to perform a feasibility study of the Munglinup graphite prospect. The prospect is 80 kilometers east of Ravensthorpe, Western Australia. Earlier diamond drilling showed graphite continuity over a strike length in excess of 600 meters. Total resources were stated to be 1.6 million tons averaging 18% carbon. Pilot plant testwork is also underway. If the feasibility study

TABLE 6

U.S. CONSUMPTION OF NATURAL GRAPHITE, BY USE

Use	Crystalline		Amorphous[1]		Total[2]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1987:[3]	13,132	$14,795	16,046	$9,082	29,178	$23,876
1988:						
Batteries	W	W	W	W	804	1,340
Brake linings	r2,601	r1,948	r2,494	r3,107	5,095	5,055
Carbon products[4]	317	879	232	374	549	1,253
Crucibles, retorts, stoppers, sleeves, nozzles	W	W	W	W	1,641	1,818
Foundries[5]	465	283	3,907	1,247	4,373	1,530
Lubricants[6]	r3,386	r4,895	r2,815	1,623	r6,201	r6,518
Pencils	r1,596	r1,947	303	174	r1,899	r2,121
Powdered metals	1,450	1,472	50	84	1,500	1,556
Refractories	W	W	W	W	7,382	4,352
Rubber	95	128	338	324	434	452
Steelmaking	188	116	1,153	1,405	1,341	1,521
Other[r,7]	2,533	5,655	455	677	2,988	6,332
Withheld uses	7,267	6,848	2,560	663	—	—
Total[r,2]	19,897	24,171	14,308	9,678	34,205	33,848
1989:						
Batteries	W	W	W	W	1,243	1,924
Brake linings	2,281	2,436	2,427	5,450	4,708	7,886
Carbon products[4]	340	886	167	242	507	1,128
Crucibles, retorts, stoppers, sleeves, nozzles	W	W	W	W	1,497	1,697
Foundries[5]	408	481	4,847	1,412	5,255	1,893
Lubricants[6]	3,391	5,033	3,125	1,068	6,516	6,101
Pencils	1,757	1,876	248	150	2,005	2,026
Powdered metals	1,401	2,551	58	111	1,459	2,662
Refractories	W	W	W	W	10,195	8,985
Rubber	72	108	406	314	478	422
Steelmaking	218	122	1,035	484	1,253	606
Other[7]	2,108	7,542	189	284	2,297	7,826
Withheld uses	7,917	9,552	4,005	2,160	—	—
Total[2]	19,893	30,587	16,507	11,675	37,413	43,156

W Withheld to avoid disclosing company proprietary data; included with "Withheld uses."

[1] Includes mixtures of natural and manufactured graphite.

[2] Data may not add to totals shown because of independent rounding.

[3] Revision reflects a data correction in the lubricant and other use categories

[4] Includes bearings and carbon brushes.

[5] Includes foundry facings.

[6] Includes ammunition, packings, and seed coating.

[7] Includes paints and polishes, antiknock and other compounds, soldering and/or welding, electrical and electronic products, mechanical products, magnetic tape, small packages, industrial diamonds and drilling mud.

TABLE 7

REPRESENTATIVE YEAREND GRAPHITE PRICES

(Per metric ton)

	1988	1989
Industrial minerals:		
Crystalline large flake, 85% to 90% carbon	$820–$1,300	$820–$1,300
Crystalline medium flake, 85% to 90% carbon	770– 1,120	770– 1,120
Crystalline small flake, 80% to 90% carbon	540– 900	540– 900
Powder (200 mesh), 95% to 97% carbon	770– 1,000	770– 1,000
Powder (200 mesh), 97% to 99% carbon	1,000– 1,300	1,000– 1,300
Amorphous powder, 80% to 85% carbon	220– 440	220– 440
Custom value, at foreign ports:		
Flake	742	951
Lump and chip, Sri Lankan	843	1,027
Amorphous, Mexican	53	114

Source: Industrial Minerals, No. 255, Dec. 1988, p. 82, and No. 267, Dec. 1989, p. 82.

TABLE 8

INDEXES OF UNIT VALUE OF GRAPHITE FIBER PRODUCED IN THE UNITED STATES[1]

(1973 = 100)

Year	Cloth and low-modulus fibers	High-modulus fibers
1978	117	66
1979	114	56
1980	125	50
1981	129	46
1982	146	48
1983	129	45
1984	146	43
1985	149	50
1986	176	51
1987	153	50
1988	179	57
1989	164	52

[1] The indexes were calculated from company data most representative of the industry and are not based solely on data shown in table 5.

TABLE 9

U.S. EXPORTS OF NATURAL AND ARTIFICIAL GRAPHITE, BY COUNTRY

Country	Natural[1]		Artificial		Total	
	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value
1988:						
Brazil	17	$5,524	284	$330,791	301	$336,315
Canada	5,989	2,093,978	12,170	638,990	18,159	2,732,968
Germany, Federal Republic of	15	3,735	2,027	737,953	2,042	741,688
Italy	20	23,518	167	197,891	187	221,409
Japan	1,500	1,314,394	4,037	3,201,325	5,537	4,515,719
Mexico	1,158	526,572	463	245,695	1,621	772,267
United Kingdom	328	276,731	1,694	1,195,560	2,022	1,472,291
Venezuela	504	382,071	224	140,754	728	522,825
Other	1,536	1,188,192	11,348	7,323,521	12,884	8,511,713
Total	11,068	5,814,715	32,414	14,012,480	43,480	19,827,195
1989:						
Brazil	8	17,452	885	1,324,786	893	1,342,238
Canada	5,936	3,032,576	14,295	4,964,881	20,231	7,997,457
Germany, Federal Republic of	156	72,316	1,860	848,464	2,016	920,780
Italy	102	211,966	268	261,984	370	473,950
Japan	572	691,249	1,905	2,734,937	2,477	3,426,186
Mexico	2,382	1,203,060	1,176	656,173	3,558	1,859,233
United Kingdom	448	189,271	3,777	2,485,322	4,225	2,674,593
Venezuela	411	686,777	90	79,166	501	765,943
Other	1,437	1,316,130	13,021	12,610,802	14,458	13,926,932
Total	11,452	7,420,797	37,277	25,966,515	48,729	33,387,312

[1] Amorphous, crystalline flake, lump or chip, and natural, not elsewhere classified.

Source: Bureau of the Census.

TABLE 10

U.S. IMPORTS FOR CONSUMPTION OF NATURAL GRAPHITE, BY COUNTRY

Country	Crystalline flake		Lump or chippy dust		Other natural crude and refined		Amorphous		Total[1]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1987	5,964	$4,683	1,272	$1,137	17,771	$10,710	18,328	$1,123	43,334	$17,654
1988:										
Austria	34	25	—	—	—	—	61	39	95	64
Brazil	2,080	1,607	—	—	2,646	2,064	—	—	4,726	3,671
Canada	2,216	1,533	—	—	2,494	1,188	—	—	4,710	2,721
China	1,186	613	—	—	13,752	6,051	138	25	15,076	6,689
France	18	22	—	—	27	78	—	—	45	100
Germany, Federal Republic of	(2)	1	—	—	248	624	—	—	248	624
Hong Kong							131	53	131	53
India	—	—	—	—	220	207	—	—	220	207
Japan	19	83	—	—	224	635	—	—	243	718
Madagascar	2,615	2,169	—	—	1,332	1,032	—	—	3,946	3,201
Mexico	—	—	—	—	1,607	869	18,794	1,000	20,401	1,869
Netherlands	—	—	—	—	6	65	—	—	6	65
South Africa, Republic of	—	—	—	—	340	188	—	—	340	188
Sri Lanka	—	—	2,819	2,376	—	—	—	—	2,819	2,376
Sweden	—	—	—	—	1	1	—	—	1	1
Switzerland	—	—	—	—	119	108	—	—	119	108
Taiwan	—	—	—	—	14	3	—	—	14	3
United Kingdom	80	63	—	—	1	1	—	—	81	64
Zimbabwe	—	—	—	—	634	410	—	—	634	410
Other	1	4	—	—	11	101	—	—	12	105
Total[1]	8,249	6,120	2,819	2,376	23,676	13,625	19,123	1,117	53,867	23,238
1989:										
Belgium-Luxembourg	—	—	—	—	50	12	—	—	50	12
Brazil	2,613	2,937	—	—	2,935	3,018	—	—	5,548	5,955
Canada	2,144	2,235	—	—	3,261	2,684	—	—	5,405	4,919
China	2,995	2,047	—	—	12,504	7,906	1,090	995	16,589	10,948
France	—	—	—	—	50	196	—	—	50	196
Germany, Federal Republic of	38	48	—	—	182	479	—	—	220	527
Hong Kong	—	—	—	—	—	—	220	43	220	43
India	36	45	—	—	431	417	—	—	467	462
Japan	46	161	—	—	411	1,646	—	—	457	1,807
Korea, Republic of	—	—	—	—	—	—	7,275	380	7,275	380
Madagascar	294	322	—	—	4,368	3,318	—	—	4,662	3,640
Mexico	71	43	—	—	1,704	229	17,073	1,939	18,848	2,211
Netherlands	—	—	—	—	22	404	—	—	22	404
South Africa, Republic of	—	—	—	—	58	66	—	—	58	66
Sri Lanka	—	—	675	693	—	—	—	—	675	693
Switzerland	—	—	—	—	66	75	—	—	66	75
United Kingdom	—	—	—	—	1	6	—	—	1	6
Zimbabwe	685	643	—	—	1,018	697	—	—	1,703	1,340
Other	—	—	—	—	3	23	—	—	3	23
Total[1]	8,922	8,481	675	693	27,064	21,176	25,658	3,357	62,319	33,707

[1] Data may not add to totals shown because of independent rounding.
[2] Less than 1/2 unit.

Source: Bureau of the Census.

is positive, the option on the property will be exercised.

Graphite Mines of Australia, a subsidiary of Solution Mining, announced that it would reopen its Uley Mine near Port Lincoln, South Australia. It will have an output of 2,500 tons per year of product. The firm plans to gradually double the mine's production and export about 75% of the product. It plans to spend around $3.8 million.

Brazil

Nacional de Grafite Ltda. is planning to increase its product capacity at Pedra Azul by building a new plant on the same site. The present capacity of 28,500 tons of product per year will increase by 18,000 tons per year in mid-1991 and by an additional 18,000 tons per year by 1992.

Canada

Stratmin Inc. was the only Canadian producer of graphite in 1989. It brought its second mine on-stream and was considering expanding its mill capacity to 30,000 tons per year of concentrate. Cal Graphite Corp. and Exploration Graphicor Inc. may come on-stream in 1990. Exploration Graphicor holds three deposits near those of Stratmin and is hoping to have a production capacity of 11,000 tons.

Societe d' Exploration Miniere Mazarin Inc. estimates that its heavily-drilled deposit near Fermont has over 8.5 million tons of an unusually rich ore averaging 17% graphite. This would be a 67 years supply at the proposed productive capacity of 20,000 tons per year. The deposit has good road access and is close to the iron ore towns of Labrador and Quebec. The firm tried to negotiate a partnership with Cassiar Mining Ltd., but was unsuccessful. The project cost was estimated to be $32 million.

Mexico

For $5.7 million, the Mexican Government sold all of Grafito de Mexico SA, its crystalline flake graphite operation. The buyer was Minerals No-Metalicos Mexicanos SA, a member of the Jose Valdes group. The capacity doubling now underway should be finished this year. The firm is planning to add an acid and pressure leaching stage that will allow it to make a 99.6% carbon final product.

Sri Lanka

Guerillas attacked the Kolongaha graphite mine towards the end of the year. They set fires that destroyed some vehicles and machinery, doing about $500,000 in damage.

TABLE 11

U.S. IMPORTS FOR CONSUMPTION OF ARTIFICIAL GRAPHITE AND GRAPHITE ELECTRODES, BY COUNTRY

Country	Artificial graphite		Graphite electrodes	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1988:				
Belgium	—	—	352	$676
Brazil	—	—	187	56
Canada	1,588	$599	9,916	12,606
China	—	—	258	376
France	769	3,326	1,495	1,983
Germany, Federal Republic of	641	2,997	5,138	7,906
Italy	203	411	4,827	7,477
Japan	1,002	8,418	21,839	33,245
Mexico	—	—	8,230	9,734
Spain	—	—	1,049	1,791
Sweden	—	—	1	75
Switzerland	4,579	9,852	499	905
Taiwan	—	—	234	267
United Kingdom	7	101	2,703	3,919
Other	4	48	212	293
Total[1]	8,793	25,751	56,940	81,309
1989:				
Belgium	—	—	306	542
Brazil	—	—	1,289	503
Canada	37	19	6,130	6,277
China	2	6	526	831
France	1	9	1,387	1,367
Germany, Federal Republic of	217	268	2,758	4,082
Italy	—	—	5,931	9,747
Japan	4	48	4,889	7,807
Mexico	190	6	11,333	14,122
Spain	—	—	525	985
Sweden	—	—	—	5
Switzerland	(2)	2	55	105
Taiwan	12	29	4	14
United Kingdom	124	810	588	928
Other	77	126	669	874
Total[1]	665	1,322	36,390	48,189

[1] Data may not add to totals shown because of independent rounding.
[2] Less than 1/2 unit.

Source: Bureau of the Census.

CURRENT RESEARCH

The Bureau of Mines examined substitutes for the crystalline flake graphite used in dolomite-carbon refractories, and the use of graphite fiber in particular. Test samples were evaluated for modulus of rupture, deformation under load, and air-slag-metal resistance. Graphite

TABLE 12

GRAPHITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Argentina	32	40	216	24	50
Austria	30,764	36,167	39,391	7,577	7,000
Brazil (marketable)[3]	27,239	28,586	31,404	32,000	30,000
Burma[4]	234	722	—	—	—
China[e]	185,000	185,000	185,000	200,000	200,000
Czechoslovakia[e]	r35,000	5 25,254	r25,000	r25,000	25,000
Germany, Federal Republic of	12,798	13,233	9,891	e7,000	7,000
India (mine)[6]	27,337	38,412	42,589	52,134	55,000
Korea, North[e]	25,000	25,000	25,000	25,000	25,000
Korea, Republic of:					
Amorphous	69,877	96,577	106,507	107,767	98,000
Crystalline flake	1,602	641	838	678	1,000
Madagascar	13,971	16,187	13,169	14,106	14,000
Mexico:					
Amorphous	33,468	r36,018	36,674	42,096	45,000
Crystalline flake	1,910	1,838	1,787	1,735	2,000
Norway	2,684	—	—	—	—
Romania[e]	12,000	12,000	12,000	12,000	10,000
Sri Lanka	7,413	7,453	9,400	8,547	5 4,163
Turkey (mine)	e5,000	3,586	11,760	12,833	13,000
U.S.S.R.[e]	82,000	83,000	84,000	84,000	84,000
United States	—	—	—	W	W
Zimbabwe	10,450	15,004	13,530	11,441	11,000
Total	r583,779	r624,718	r648,156	643,938	631,213

[e] Estimated. [p] Preliminary. [r] Revised. W Withheld to avoid disclosing company proprietary data.

[1] Table includes data available through May 8, 1990.

[2] In addition to the countries listed, Canada produced graphite during the period covered by this table, but output is unreported.

[3] Does not include the following quantities sold directly without beneficiation, in metric tons: 1985—16,425; 1986—19,074; 1987—10,505; 1988—20,000 (estimated); and 1989—20,000 (estimated).

[4] Data are for fiscal year beginning Apr. 1 of that stated.

[5] Reported figure.

[6] Indian marketable production is 10%-20% of mine production.

fiber at the 1.5% level was added to sample dolomite-carbon brick. The resulting physical properties were generally comparable to those obtained with natural flake graphite, but were below those obtained with 10% flake graphite additions. Therefore, graphite fiber was shown to be an unsatisfactory substitute for flake graphite.[1]

The U.S. Air Force sponsored a major conference on the occupational health aspects of advanced composite materials use in the aerospace industry in Dayton, OH in February.

OUTLOOK

Projected demand for crystalline flake graphite totaled 23,000 tons for 1995 and 25,000 tons for 2000. Demand for other graphite, mostly amorphous, totaled 12,000 tons for 1995 and 10,000 tons for 2000. This relatively slow rate reflects the maturity of the market, mostly in refractories, and particularly in carbon-magnesite brick. The supply situation, previously described, is unusually cloudy and appears likely to stay that way for at least several years.

BACKGROUND

Graphite, a soft crystalline form of carbon, has been called plumbago and black lead. It crystallizes in a lamellar hexagonal system, has a gray to black metallic luster, and is greasy to the feel. It is anisotropic in its physical properties and has a weak plane of cleavage parallel to the lamellae.

The term "amorphous" when applied to graphite is a misnomer. The term "microcrystalline" is more descriptive. The definition of amorphous, as applied to graphite, has been further complicated by longstanding industrial application of the term to very fine particles of crystalline flake graphite which can be sold only for low-value uses such as foundry facings. Fine-grained varieties of lump graphite that are easily reduced to fine particle size by grinding are called amorphous lump, to distinguish them from the tough, platy and acicular varieties, known as crystalline lump, that can be reduced in particle size only with extreme difficulty.

Crystalline flake graphite is well defined in paragraph 214 of the Tariff Act of 1930 as follows:

"The term crystalline flake means graphite, or plumbago, which occurs disseminated as a relatively thin flake throughout its containing rock, decomposed or not, and which may be or has been separated therefrom by ordinary crushing, pulverizing, screening, or mechanical concentration process, such flake being made up of a number of parallel laminae, which may be separated by mechanical means."

Under the foregoing definition, finely divided particles of crystalline flake graphite would be classified as crystalline graphite. However, the Court of Customs Appeals has reportedly held that commercial designations and not scientific terms must govern classification and when a commercial meaning differs from the technical meaning the commercial designation must govern. Thus, quantities of fine crystalline flake graphite are imported under the other Natural Crude and Refined classification.

Sri Lankan lump graphite is classified as amorphous or crystalline. Each type is divided into a number of grades, depending upon the size (such as lump, ranging from the size of walnuts to that of peas; chip, from that of peas to about that of wheat grains; and dust, finer than 60 mesh), graphitic carbon content, and degree of consolidation.

Amorphous graphite is graded primarily on graphitic carbon content. Commercial ore contains about 75% to

93% carbon, depending on the source.

Crystalline flake graphite from Madagascar is divided into two main grades, "flake" (coarse flake) and "fines" (fine flake). Madagascan crucible flake must have a minimum of 85% graphitic carbon and be essentially all minus 8 plus 60 mesh in particle size. Other crystalline flake graphites are also graded according to graphitic carbon content and particle size.

Natural graphite is marketed in the form of crystalline graphite as flake, lump, chip, and dust and in the form of amorphous graphite in sizes from fine powder to lumps up to the size of walnuts. It is common practice to blend different graphites to obtain a product having certain desired physical and chemical properties. In many instances, the composition of these blends is retained as a trade secret.

GEOLOGY—RESOURCES

The three principal types of natural graphite—lump, amorphous, and crystalline flake—are based on physical characteristics that are the result of major differences in geologic origin and occurrence. A variety of silicate minerals are generaliy associated with graphite in the ore.

Lump graphite occurs as fissure-filled veins. It is typically massive, ranging in particle size from extremely fine grains (amorphous) to coarse, platy intergrowths of fibrous to acicular aggregates (crystalline). The origin of vein-type graphite deposits is believed to be hydrothermal and/or pneumatolytic.

Amorphous graphite is formed by metamorphism of coalbeds by nearby intrusives. Its purity depends on the purity of the original coalbeds. Amorphous graphite usually is associated with sandstones, shales, slates, and limestones.

Flake graphite commonly occurs disseminated in regionally metamorphosed sedimentary rocks, such as gneisses, schists, and marbles. It is believed that the graphite was formed under the same conditions that caused the metamorphism of the rocks—from carbon deposited with the sediments.

Although the flake graphite deposits of certain countries conform to this description, the commercial deposits that are exploited are alluvial, lateritic clays that have accumulated at the surface. Graphite, quartz, and other resistant minerals have been freed by kaolinization of the feldspars, lessening the amount of crushing necessary before beneficiation.

World graphite reserves totaled 21.0 million tonnes. Detailed breakouts are given in the 1988 Mineral Yearbook chapter.

TECHNOLOGY

Mining

In Sri Lanka, lump graphite is mined underground from narrow, steeply dipping veins. The ore is mined principally by overhand stoping and filling, using temporary stulls when necessary to support the walls. Hand drilling is used in most stoping to achieve selective mining and to avoid unwanted fines and product contamination. Air drills are used in development headings. The ore is hauled by truck to the sorting and classification yard.

Amorphous graphite beds also are usually mined underground, however, the beds are much thicker than those of amorphous lump and crystalline lump. The ore is drilled, blasted, handloaded into cars, and hauled to the surface by conventional methods.

Flake graphite deposits have been mined by underground and surface methods. Underground deposits are usually unweathered and require drilling and blasting. Most surface mining is confined to the weathered part of the deposit, and normal excavating equipment such as power shovels, bulldozers, and rippers is used with a minimum of drilling and blasting. The ore is usually trucked to the mill.

Milling

Sri Lankan amorphous and crystalline lump graphites are refined by hand cobbing and sorting, and wiping lumps on wet burlap to remove fines. Light hand sorting and cleaning operations are done by women, while the heavier duties are performed by men.

Most amorphous graphite that requires beneficiation is not worth mining. Preparation for most uses requires grinding only, and coarse impurities are removed by screening or air separation methods.

Flake graphite from disseminated deposits must be concentrated to meet market requirements. Virtually every known concentrating device and combination of separating principles have been tried. The mineral has gained a reputation of being difficult to concentrate, and probably in no other industry has such a large proportion of the mills failed to make commercial recoveries. Graphite actually is one of the easiest minerals to segregate into a rough concentrate, but one of the most difficult to refine.

Graphite floats readily and does not require a collector; hence, froth flotation has become the accepted method for beneficiating disseminated ores. The chief problem lies with depressing the gangue minerals. Relatively pure grains of quartz, mica, and other gangue minerals inadvertently become smeared with the soft, fine graphite, making them floatable and resulting in the necessity for repeated cleaning of the concentrates to attain high-grade products.

ECONOMIC FACTORS

The price structure of graphite is quite complex because of the wide variety of products and the lack of standard market quotations. Prices quoted in trade journals are only a range negotiated between buyer and seller. These quotations are available in Industrial Minerals, Chemical Marketing Reporter, and the Bureau of Mines Minerals Yearbook. However, average declared import values per ton for amorphous and crystalline graphite have been available for years from Bureau of the Census data.

The cost for domestically produced graphite from new mines would be much higher than that for graphite from the major foreign sources, for the same type and purity, chiefly because of high labor costs and the low graphite content of the ore.

Employment and Productivity

Production of marketable natural graphite requires little hand labor, except for the graphite mined in Sri Lanka. Even in areas of low-cost labor, mechanical methods are used to mine

and concentrate flake graphite.

Because of the small size of the domestic natural graphite industry, no publishable employment data are available. Since there is only one small mine and the product is beneficiated and processed to a minimal extent, employment probably does not exceed 50. Much of the imported graphite requires grinding, perhaps further refining, mixing with other grades to meet consumer specifications, bagging, and shipping. The total number of persons engaged in these operations, including marketing, probably does not exceed 500.

Taxes and Tariffs

Graphite producers are granted a 22% depletion allowance for tax purposes on domestic lump and amorphous and 14% on domestic flake and on foreign operations.

Duties on graphite items imported from most favored nations (MFN) are minimal. Graphite from the U.S.S.R. and certain other nations is subject to a higher duty.

TABLE 13

U.S. IMPORT DUTIES

Tariff item	No.	Most favored nation (MFN) Jan. 1, 1990	Non-MFN Jan. 1, 1990
Crystalline flake, (not including flake dust):	2504.10.10	0.7 cents per kilogram	3.6 cents per kilogram.
Other powder	2504.10.50	Free	10% ad valorem.
Other	2504.90.00	Free	Do.

OPERATING FACTORS

Natural graphite is an inert nontoxic substance and environmental requirements are limited to dust control and certain organic vapors arising from ingredients blended with it to manufacture products.

[1] Bennett, J. P. Effect of Natural Flake Graphite and Carbon Fiber Additions on High-Temperature Properties of Dolomite-Carbon Refractories. BuMines RI 9275, 1989, 16 pp.

OTHER SOURCES OF INFORMATION

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Chemical Week.
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